REGIONAL PRODUCTIVITY AND EFFICIENCY IN THE U.S.: EFFECTS OF BUSINESS CYCLES AND PUBLIC CAPITAL

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by

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ABSTRACT

Previous research on the slowdown of U.S. productivity growth suffers a common weakness by assuming economic agents adjust instantaneously to altered market conditions. This may lead to biased estimates. We avoid this problem, adapting a technique that allows decomposition of productivity growth into efficiency change and technological innovation. The Malmquist index measures each component for each observation, which allows exploration of factors that may lead to differences in the productivity components across regions. We consider the effects of business cycles, both own-state and cross-border public infrastructure investment, and relative sizes of the manufacturing, service and public sector.

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1. INTRODUCTION

Over the last two decades considerable attention has been paid to the dramatic slowdown in productivity growth in the United States, both relative to its past performance and in comparison to industrialized trading partners. A related issue has been the economic decline of older regions of the U.S. and the development of the Southern and Western states. These productivity declines are responsible for decreased living standards, growth in the trade and budget deficits, as well as increasing the size of the underclass. While much evidence has been offered attesting to the magnitude of these events (see, for instance, Darby (1984), Litan, Lawrence and Schultze (1988), Kendrick (1980), or Morrison (1992)) we still know very little about the causes of productivity changes.[1]

One explanation that has received greater focus has been the coincident decline in infrastructure investment in the U.S. overall, and differences in that investment between geographic regions. Hulten and Schwab (1991) apply a "sources of growth" methodology to measure productivity growth and to estimate the impact of public capital. They find that productivity has a strong impact on economic growth in all regions, but variations between regions are almost completely explained by differences in growth rates of private inputs. Thus, there is little, if any, explanatory power for infrastructure's impact on productivity growth. Similarly, Holtz-Eakin (1994) reports no discernible difference between regions in terms of public capital's effect on gross state product. Contrarily, Aschauer (1989a, b, c) presents results which point to large, positive impacts of

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[1]Some researchers have merged the issues (see Hulten and Schwab (1984) and Olson (1983)) to study the impact of changing productivity on economic growth.

infrastructure investment on productivity. Munnell (1990a, b) reveals a major role for public capital as a determinant of regional economic growth, with a particularly strong impact in the South.

Hulten and Schwab (1991) have noted that it is reasonable to expect that infrastructure investment in one region of a "network" affects output in other regions of the network. They suggest that some means of accounting for public capital in other regions "may be ... more appropriate" than simply incorporating only the 'target' region's infrastructure (p. 126). Regardless of whether we consider public goods to be pure or congestable the influence of infrastructure is not likely confined within geopolitical boundaries. Holtz-Eakin and Schwartz (1994) have examined production when allowing for potential spillovers of the effects of highway capital stock across state lines and found that on average there is no statistically significant effect on productivity from either own-state or from neighboring states' infrastructure investment.

There is a common weakness shared by those studies that use (a variation of) Solow's (1957) growth accounting technique. Each is conducted under the assumption that observed factor income shares are equal to output elasticities, implying that factors are paid their marginal product, and that there is instantaneous adjustment to altered market conditions. To the extent that this does not hold then conventional estimates of TFP change may be biased. In this case, firms may be technically or allocatively inefficient in the use of inputs. This, in turn, implies that observed input-output combinations may lie below the frontier of production technology. In such a case, TFP may change as a result of (dis)improved efficiency, that is, a movement (away from) towards the frontier. This is in stark contrast to the growth accounting approach, which holds that observed output is equivalent to frontier output, and that growth in TFP is comprised only of technological progress, that is, shifts in the frontier.[2]

In this paper, we follow Färe, et al. (1994) by adapting a technique that allows productivity growth to be decomposed into two mutually exclusive and exhaustive components: changes in technical efficiency over time, and shifts in the technology over time resulting from adoption of new techniques. In this study, the latter change reflects technical innovation as practiced by 'state of the art' firms, while the former represents (dis)improvement in the means by which known technology is applied in production.[3] We use the Malmquist (1953) total factor productivity index and include own-state public infrastructure capital stock as an input to the production process. This approach allows us to disaggregate and decompose the effects on productivity for each observation in the sample, not just average effects, which is a limitation of previous research. We can examine the characteristics of those states and regions whose productivity levels are higher and describe the characteristics of states (regions) that use their infrastructure investment more productively.

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[2]Hulten (1986), and Berndt and Fuss (1986) develop productivity growth measures that allow for capacity underutilization resulting from the sluggishness of quasi-fixed inputs to freely adjust to changes in input prices.

[3]Nishimizu and Page (1982) and Bauer (1990) have employed similar decompositions of TFP growth. The former estimate a single valued frontier production function, and the latter estimates a stochastic frontier cost function. Here we use multiple output distance functions to construct a Malmquist productivity index.

To this end, we consider several possible influences on productivity and its components. First, we investigate the effects of business cycles. Since it is reasonable to expect regional economies to be neither perfectly harmonious with nor independent of each other, then differences in productivity responses to cyclical fluctuations should be evident. In particular, higher growth regions are likely to exhibit tendencies for adoption of technical innovations, while lower growth or even declining regions may reveal efforts at improved efficiency. Second, variation across regions in terms of the magnitude of the service sector relative to manufacturing may lead to different rates of technological adaptation and/or ability to efficiently utilize inputs. Third, differences across regions in the ratio of private capital to labor might be expected to exert varying influences on efficiency and technical change. We hypothesize that regions with higher proportions of capital to labor will have a propensity towards using the latest, state of the art technology and/or attaining maximal efficient use of inputs. Similarly, differences in the ratio of highway capital stock to private capital stock as well as the ratio of other forms of public capital to private capital may impart diverse affects on the components of productivity change. For instance, states with larger highway to private capital ratios are conjectured to experience larger productivity impacts since private firms use the "free" public good to augment production. Fourth, states with large private sectors relative to their total economy are hypothesized to be more efficient, experience greater technological innovation and adaptation of public capital. Fifth, we consider Hulten and Schwab's (1991) "network" affect by measuring the impact of neighboring states' highway capital on "home" state productivity and efficiency.

2. THE PRODUCTIVITY INDEX

The measure we use to analyze productivity performance of U.S. state economies is the Malmquist productivity index. This index was introduced by Caves, Christensen and Diewert (1982) as a theoretical construct based on distance functions. They showed that this index was equivalent (under certain conditions[4]) to the Törnqvist index, which is the discrete counterpart of the Solow growth accounting model. The Törnqvist index does not require estimation of distance functions, but rather aggregates inputs and outputs by weighting them by their shares. Unlike Caves, Christensen and Diewert, we follow Färe, Grosskopf, Lindgren and Roos (hereafter FGLR) (1989), by calculating the Malmquist index directly, exploiting the fact that the distance functions upon which the Malmquist index is based can be calculated as reciprocals of Farrell (1957) technical efficiency measures. As shown in FGLR, this allows the decomposition of productivity into changes in efficiency (catching up) and changes in technology (innovation).

More formally, if there are $x^t = (x^t_1,\dots,x^t_N)$ inputs at period $t=1,\dots,T$ that are used to produce outputs $y^t = (y^t_1,\dots,y^t_M)$, then the technology at t consists of all feasible (x^t,y^t), i.e.,

$$S^t = \{(x^t,y^t): x^t \text{ can produce } y^t\}. \tag{1}$$

The output distance function is due to Ronald Shephard (1970) and is defined[5] relative to the technology S^t as

[4]These include: technology is translog, second order terms are constant over time, firms are cost minimizers and revenue maximizers.

[5]See Färe (1988) for a detailed discussion of input and output distance functions.

$$D^t_o(x^t,y^t) = \min\{\theta : (x^t,y^t/\theta)\epsilon S^t\},\ x^t\epsilon \mathbf{R}^N_+,\ t=1,...,T. \tag{2}$$

Given x^t, the distance function increases y^t as much as possible (by scaling it by θ) while remaining in S^t. We note that there is a close relationship between the distance function and the Farrell output based measure of technical efficiency. Specifically:

$$\begin{aligned} D^t_o(x^t,y^t) &= \min\{\theta : (x^t,y^t/\theta)\epsilon S^t\} \\ &= [\max\{\theta : (x^t,\theta y^t)\epsilon S^t\}]^{-1} \\ &= 1/F^t_o(x^t,y^t), \end{aligned}$$

where $F^t_o(x^t,y^t)$ is the Farrell output based measure of technical efficiency (Farrell, 1957).

To illustrate the construction of the technology S^t from observed data, we borrow a simple example from Färe, Grosskopf, Lindgren and Poullier (1993). Suppose that one input is used in the production of one output and that there are two observations A and B, described by the following data:

	A	B
x	2	5
y	3	5

B uses more inputs than A to produce more output, but B's average productivity (y/x) is lower, i.e., $y_A/x_A = 3/2 > y_B/x_B = 1$. The reference technology is created from both observations, but the frontier is formed by the observation with the highest average product, firm A, as depicted in Figure 1. Since A is the best practice firm here, under constant returns to scale, B is compared to A in terms of average product. Thus, the value of the distance function for B will be the ratio of observed to maximum potential output

$$D_o(x^B,y^B) = 2/3,$$

since

$$\frac{y^*_B}{x_B} = \frac{5/D_o(x^B,y^B)}{5} = 3/2 = \frac{y_A}{x_A},$$

where $y^*_B = y_B/D_o(x^B,y^B)$, i.e., maximum potential output. Also note that $D_o(x^A,y^A) = 1$.

The Malmquist productivity change index computed here is based on the simple idea illustrated above, but it allows comparisons between two periods. Again, distance functions are used to provide a measure of deviations from maximum average product. Specifically, following FGLR, we define the Malmquist index of productivity change as[6]

TFP

how well you improved w/ 2 different bases

Fisher Ideal Form

$$M_o^{t,t+1} = \left[\frac{D_o^{t+1}(x^{t+1},y^{t+1})}{D_o^t(x^t,y^t)}\ \frac{D_o^t(x^{t+1},y^{t+1})}{D_o^{t+1}(x^t,y^t)}\right]^{1/2}. \tag{3}$$

geometric mean between two time periods

Paasche Laspeyre

As shown by FGLR, this index can be decomposed into two components: efficiency change and technological change as defined below:

ratio of average product

better or worse catching up to frontier

EC ↑ / TC

$$\text{Efficiency Change (EC)} = \frac{D_o^{t+1}(x^{t+1},y^{t+1})}{D_o^t(x^t,y^t)}, \tag{4}$$

1-EC / 1-TC

higher AP

$$\text{Technological Change (TC)} = \left[\frac{D_o^t(x^{t+1},y^{t+1})}{D_o^{t+1}(x^{t+1},y^{t+1})}\ \frac{D_o^t(x^t,y^t)}{D_o^{t+1}(x^t,y^t)}\right]^{1/2}, \tag{5}$$

or

EC-1 / TC-1

$$M_o^{t,t+1} = EC \cdot TC \tag{6}$$

wtd average

how great the frontier shifted out due to tech improvement; new micro improvements adopted by the observation

Right shift in ...

ΔEC / EC

ΔTC / TC

[6]See also Färe, Grosskopf, Norris and Zhang (1994) for a more accessible exposition of the Malmquist index and the technique used here to calculate it.

ΔEC-EC / EC

T2-T1 / T1

We calculate the component distance functions of the Malmquist index using programming methods which are equivalent to the nonparametric methods used in data envelopment analysis (DEA).[7] This technique constructs a 'grand' frontier based on the data from all of the observations in the sample, sometimes referred to as the best practice frontier. As illustrated in Figure 1, the best practice frontier is determined by the observations with the highest average product or productivity. Each observation is compared to that frontier. How much closer an observation gets to the frontier is dubbed catching up; how much the frontier shifts at each observation's observed input mix is due to technical change or innovation. The product of these two components yields a frontier version of productivity change. Since these can be calculated without using expenditure or price data, confounding price and quantity changes over time can be avoided. The linear programming problems we compute are included in the appendix.

3. DATA AND MODEL SPECIFICATION

The Malmquist index is based on distance functions which, as shown in the previous section, are specified in terms of input quantities and output quantities. They are, in intuitive terms, a multiple output generalization of a production function. We would like to specify a fairly general technology, one in which a state's own public infrastructure can be included as an input.

We use the same data as Munnell (1990a,b), which is a panel of 48 states (Hawaii and Alaska are excluded) over the 1970 to 1986 period. Although our model could

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[7]See Charnes, Cooper, and Rhodes (1978).

$$\frac{\frac{T_2}{T_1}-1}{\frac{E_2}{E_1}-1}$$

accommodate multiple outputs, the data we use has a single output, namely gross state product. The inputs we use include the value of own-state public capital stock (see Appendix A of Munnell (1990a) for details), the value of private sector capital, non-agricultural employment. Again, our model does not require specification of variables in value terms; the data were constructed in those terms. All monetary values are in 1982 dollars.

Thus our component distance functions include a measure of aggregate output, and three input variables, one of which is used to capture public sector effects. We use mathematical programming to construct the technology and compute the individual distance functions necessary to construct the Malmquist index. The index is computed for each state for every 'period' (i.e., for every two adjacent periods, t and t+1). Each state is compared to the portion of the 'grand frontier' that most closely resembles its own mix of inputs and output. The frontier is determined by the 'best practice' observations in the sample.

The cumulated productivity indexes and components are reported in Table 1 for each state. These represent the cumulated productivity change from 1970 to 1986. Values greater than one indicate improvements; values less than one reflect declines in performance. For most states both EFFCHCUM and TCCUM exceed one, indicating there has been greater output for given inputs as well as incorporation of production-enhancing techniques. However, some states exhibit declined productivity over the sample years. For instance, New Mexico experienced improved efficiency, but failed to maintain "state of the art" technology, such that the lagging performance in technical change outweighed improvements in efficiency. Conversely, Pennsylvania suffers diminished efficiency, but advancement in technological capacity. As a further example, Montana simultaneously experiences relatively large positive efficiency change and negative efficiency change which, on net, yields about average productivity improvement. These examples clearly illustrate the advantages of a decomposable productivity measure: in our case, states perform differently in terms of their ability to adapt to change.

Table 2 provides some descriptive data concerning variables used to calculate the productivity indexes as well as summary measures of those indexes. Turning first to growth rates of the basic data, we see that output increased on average 3.1% per year over the 1970-86 period. Private capital grew at almost twice the rate of highway capital on average, while employment grew at an even higher rate. The information disaggregated by region exhibits considerable variation. Average annual employment growth is suggestive: it increased by 3.7% per year in the West and only 1.8% in the North Central region. These two regions also had the highest and lowest rates of output growth, respectively. Furthermore, the regions with the highest employment growth (West and South) also experienced the largest highway capital growth and the highest growth in GSP, despite significant differences in private capital growth. Interestingly the East had the highest rate of growth in private capital and the lowest in public capital, but a high rate of GSP growth.

As discussed above, differences across regions in technical and efficiency change may be a function of variations in the underlying structure of the regions' economies. In Table 2 we provided descriptive statistics for variables that may influence this. The service sector's share of gross state product relative to manufacturing's varied slightly across regions, with the East and South experiencing larger average annual growth rates and the West the lowest. Given the low magnitude of the private capital to labor ratio it is difficult to comment on differences. The negative growth rates for highway and other public capital relative to private capital may be deceiving: private capital has grown at a faster rate, but all three forms of capital have had positive growth.[8] As we are particularly interested in the effect of cross-border spillover effects of infrastructure we present a measure of public sector capital in neighboring states (NEIGHBORS).[9] There is an interesting pattern in the numbers: regions with larger absolute changes in public to private capital ratios exhibit higher GSP growth. The implications of these differences will be analyzed below.

The productivity data in Table 2 give the cumulated growth over the entire period. Thus, productivity increased by 5.7% (averaged over all states) from 1970 to 1986. The biggest productivity gain occurred in the East region (1.091), and the lowest in the West (1.019). Thus, the high rate of output growth in the West was not accompanied by high productivity growth. The North Central region improved largely due to improvements in efficiency and, in fact, led all regions in doing so. The East was the leader with respect to technical innovation, but exhibits a balanced approach in terms of efficiency and

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[8]"Other" public capital is comprised of stock values of water and sewer systems, educational facilities (lagged ten years), and utilities. The education and utilities data were provided by Douglas Holtz-Eakin.

[9]This was constructed from the data available in Munnell on the stock of highways in each state. We use the weighted sum of the state highways contiguous to a given state, where the weight is the area of each respective state.

technical change. Contrarily, the West experienced unbalanced change, actually falling behind in technological innovation.[10]

To better understand these differences, we regress each of our change in productivity measures — equations (4), (5) and (6) — (not cumulative productivity) on several explanatory variables. First, we are interested in knowing whether boom periods impact productivity differently than recessionary periods. We construct for each state two dummy variables which reflect the business cycle for that state. If the growth in GSP is greater (less) than one standard deviation from the mean growth rate, the BOOM (RECESSION) variable takes a value of one. We also include various measures of the relative importance of private and public sector capital, both own-state and that of neighbors, as well as the relative importance of the service and private sectors. These measures are entered in levels, not as growth rates. We estimate the model using a random effects approach (Fuller and Battese (1974) method estimated by SAS). Thus, we interpret each coefficient as referring to the effect of the corresponding independent variable on "average" state productivity change (averaged both across time and states). We estimate this model for the Malmquist index and its two components separately.

[10]Our finding of relatively high cumulative productivity gains in the South differs from the results of Morrison and Schwartz (1994), who find the South to have relatively low productivity growth over the period 1971-1987. In contrast to our work, they use a cost function approach.

industry variation

The results (displayed in Table 3a, b, and c) are generally consistent with our averaged raw results (Table 2) and standard intuition.[11] For the RECESSION variable the coefficients are negative and (in most cases) highly significant for all regions and all components of productivity. Thus, not only does production decrease, but (firms in) states respond by becoming less efficient in the use of resources (see Table 3b). This is to be expected given idle capital during an economic downturn. The North Central appears to be most affected in this respect and the South least. That is, the South's level of efficiency does not diminish by as much. We note that the East's change in efficiency is not significantly different from zero.

During a recession firms in all regions exhibit diminished propensity to adopt new technology. The negative coefficients in Table 3c should not be interpreted as a decrease in technological capacity (i.e., a shift inward of the production possibility frontier) but instead as a decrease in the rate of technical innovation. There appears to be little variation across regions in this regard: technical experimentation may be a homogeneous "behavioral" characteristic.

Results in Table 3b show us that during prosperous times firms are more efficient in their utilization of inputs, such that output expands by a greater proportion than do

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[11]We tested whether there is a difference in coefficient values across regions by conducting Chow tests on "pooled regions." That is, an F-test was calculated for the East and West regions together relative to them separately for the Malmquist, Efficiency Change, and Technical Change Regressions. This was repeated for all combinations of East, West, North Central and South. In only four cases could we not reject the null of no significant difference between regression values — for Efficiency Change, West-South and North Central-South; for Technical Change, East-South and West-North Central. In all other cases, at the 0.01 level of significance or better, we find a difference.

productive factors. We note again that the North Central is quite responsive whereas the East's relatively low value indicates a more stable course of conduct.

A salient difference between the productivity effect of a boom and a recession is evident when we consider technical change (Table 3c). In all regions the coefficient for boom is not statistically different from zero. We had thought that firms would innovate more actively during expansionary phases. However, our results may reflect a more cautious, approach by firms, one that is not overly optimistic. Our reasoning is as follows: the definition of the BOOM variable implies that the set of non-boom periods includes some growth years also. Thus, firms may incorporate new technology at about the same rate during boom periods as during non-boom growth years, which might lead to an insignificant coefficient for BOOM. If this is the case, firms are simply practicing a steady (smooth) assimilation of technological improvements during growth years and do not accelerate the rate of improvement during boom years.[12]

To determine whether there are differences across regions in the response of a productivity measure during a boom or recession we analyzed additional regressions. We first combined the data for East and West regions, then created dummy variables for a boom and recession in the East. We then regressed each measure of productivity on our original variables plus the two new ones. We did this for each possible combination of regions. We found the East to be uniformly less responsive during recessions with

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[12]Our conjecturing is reasonable. We calculated a t statistic to test the equality of growth rates for the boom and non-boom (positive growth) subsamples. We could not reject the null of equality even though there was, on average, a difference of about 0.4 percent.

respect to technical change and more responsive during booms relative to both the North Central and South. (A similar conclusion can be reached by comparing coefficient values across regions for the BOOM and RECESSION variables in Table 3c). Concerning efficiency change (Table 3b) the South and East are less responsive than the North Central during booms, but the North Central is less responsive than the West. During recessions the North Central is less responsive than the East and South.

To further investigate the impact of the business cycle on productivity we asked: within a region is there a difference in the magnitude of the impact of a recession versus a boom on productivity? To answer this we constructed a dummy variable that takes the value of one when a state is experiencing either a boom or recession, but the value of zero when growth in gross state product is not one standard deviation from the average growth rate. Regressing our productivity measures on this dummy (and our original explanatory variables) we interpret a positive coefficient value as indicating the marginal effect of a boom is stronger than that of a recession. A coefficient that registers as not being significantly different from zero would imply the two effects are (approximately) equal. We found that only the South and North Central experience a non-neutral effect — both regions' technical change component is more responsive during recessions than booms. For efficiency change and (overall) productivity change (Malmquist) all regions exhibit neutral effects. In general, we find that firms respond in similar ways to both "extremes" of the business cycle: they do not overreact to one or the other.

Moving on to the other coefficient values in Table 3, we are surprised that the coefficient on the Service/Manufacturing ratio is significant only in the North Central region for technical change and in the South for efficiency change. The positive value for the North Central's technical change indicate that as the relative size of the service sector increases the production possibilities of that region are expanded. The "rusting" of manufacturing in that area of the Snowbelt appears to be compensated for by the benefits associated with development of the service sector. The negative coefficient on efficiency change implies that the South has not been able to adapt completely in response to the changing service/manufacturing sectoral configuration. For the other regions, coefficients for both technical and efficiency change are not statistically different from zero. As Table 2 shows, the service sector has grown relative to manufacturing in all regions with some difference in rates. It appears, however, that the transformation towards a service-oriented economy has not disrupted, or distorted, firms ability to maintain efficiency or adapt to changing technology. Another way to interpret these zero coefficients is to say that states (regions) with higher service to manufacturing ratios are no more or less adept than lower ratio states at managing changes in efficiency and technology.

In Table 3a we observe that regions (states) with higher private capital to labor ratios experience lower levels of productivity (although the magnitude of the relation is quite small). This would seem to indicate an overinvestment in capital, a conclusion supported by the results in Table 3c. There we find that the negative coefficients reported for the overall productivity index (Malmquist—Table 3a) are determined by negative technical change effects. States with higher capital to labor ratios are not as able to adopt technological innovations. Interestingly, the mix of private capital and labor does not impact efficiency in production; low and high ratio states perform similarly when comparing actual to potential output.

The coefficient values for the (own-state) highway to private capital stock ratio reveal mixed results. The Malmquist index values (Table 3a) indicate no statistically significant relation. However, the decomposed indexes disclose opposing forces. In Table 3b we see that states (regions) with higher highway to private capital ratios are more efficient — that is, their actual output is closer to potential output. This is evidence of spillovers of own-state public capital to private sector productivity. But the negative coefficients in Table 3c, were they significant, would imply that greater (relative) amounts of highway infrastructure do not foster technological progress but, instead, lead to diminished rates of such advancement. This latter result may indicate overinvestment in highway capital stock.

The mixed and statistically insignificant values for the Public Capital to Private Capital ratio in Tables 3a, b, and c suggest that other forms of (within-state) government provided infrastructure do not affect productivity or efficiency of firms.

The larger the private sector as compared to total (state) economy the smaller the public sector share. Thus, considering reports in the popular press of the inefficiency of government it is not surprising that Table 3a displays a strong impact for Private Sector share on productivity in all regions. What is surprising is the wide range of coefficient values, especially when we consider the uniformity of growth rates across regions in private sector share (see Table 2). Analyzing Tables 3b and c we find the source of these relations differs by region. Only in the North Central does private sector share affect efficiency, such that the higher the share the more efficient is production. In no region does relative size of the private sector have an influence on technological innovation.

In the East and South the larger the neighbors' highway infrastructure the smaller the spillover impact on a "home" state's productive capacity. In other words, adjacent states' highway systems have more of an influence on productivity in those states whose neighbors have relatively less highway stock per square mile.

4. Conclusion

Measuring productivity change by means of a decomposable Malmquist index allows a more complete examination of the underlying factors. Since the value of each component — efficiency and technical change — is calculated we are presented with a breakdown of the forces that shape productivity change. Moreover, as these values are reported for each observation the results can be further examined for characteristics that contribute to variation across observations.

In particular, we find that during recessions productivity decreases as a result of diminished efficiency and incorporation of technical innovation. However, during booms it is improved efficiency that leads to increased productivity. We also find substantial variation across regions of the effects of booms and recessions on each productivity component. For instance, the East is considerably less affected by business cycle variations with respect to efficiency changes. Yet, during booms the East outpaced other regions in innovation of technology.

Other results include: the size of the service sector relative to manufacturing is not an important determinant of (any component of) productivity; regions with higher private capital to labor ratios experience lower levels of productivity growth; states with relatively small public sectors are more efficient; and, there is evidence of (own-state) public capital spillover effects on private sector productivity.

Our results concerning neighborhood spillover effects agree with those reported by Holtz-Eakin and Schwartz (1994) and Kelejian and Robinson (1994). Using various specifications of the Cobb-Douglas production model to account for econometric issues such as state-specific fixed effects, spatial correlation and endogeneity of inputs these authors consider the effect of own-state and neighboring states' highway capital on production. In general, they find that only in the most simplistic models can support be offered for spillovers, whereas in econometrically "more correct" models the impact is either statistically insignificant or negative. Contrarily, Munnell (1990b) also adopts the Cobb-Douglas model and treats the intercept as a measure of the level of technology (i.e., as an adjustment to productivity). She reports positive effects of government capital on output. She also points out that the contributions to output attributable to private capital and labor appear to be augmented, or enhanced, by public capital. Neither she nor the other authors attempt to measure this influence directly.

All of these authors estimate the marginal impact of infrastructure on production without taking into account other means by which spillovers might have an impact. We have captured the impact of public capital on changes in resource utilization and technological innovation. Since they estimate only the marginal impact they have passed over the cross-input adjustment processes that affect production.

Another way in which our work differs is that we directly measure change in productivity and efficiency resulting from variations in own-state public capital, private capital and labor as well as neighboring states' highway capital. The aforementioned researchers estimate the effect these changes have on production — that is, output — not productivity. Thus, any comments addressing productivity impacts can only be inferential. In other words, they have found that public capital does not appear to affect private sector output, whereas we show it does not impact productivity.

A further advantage of our work is that we calculate estimates of efficiency and technical change for each state in each time period. Other studies, for instance those using the Cobb-Douglas technology, can only report an average effect. This may be why they find the impact of infrastructure is not significantly different from zero: it may be that there are many states with positive effects, many with negative effects and even some with no effect, which leads to, on average, no effect. Our methodology allows us to explore this issue and search for characteristics that explain variations.

APPENDIX

To calculate technical change and efficiency change we compute distance functions for the following type: for each state, $k'=1,\ldots,K$ and period $t=1,\ldots,T$,

$$[D_o^t(x^{k',t},y^{k',t})]^{-1} = \max_{(\theta,z)} \theta$$

$$\begin{aligned} \text{s.t.} \quad & \theta y_m^{k',t} \le \Sigma_{k=1}^{K} z^{k,t} y_m^{k,t}, \quad m=1,\ldots,M, \\ & \Sigma_{k=1}^{K} z^{k,t} x_n^{k,t} \le x_n^{k',t}, \quad n=1,\ldots,N, \\ & z^{k,t} \ge 0, \quad k=1,\ldots,K, \end{aligned} \tag{8}$$

where y is output (in our case a scalar, i.e., $M=1$), and x_n is the vector of nonspillover inputs.

The z's and the θ are variables for which we solve. The z's serve the purpose of constructing the reference technology as convex combinations of the data. The inequalities allow for the usual assumption of strong (or free) disposability of outputs and inputs.

The other three components are calculated similarly, substituting the appropriate period data (i.e., t or t+1).

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TABLE 1
Cumulated Indexes, 1970-1986

STATE	MALMCUM	EFFCHCUM	TECHCHCUM
ALABAMA	1.142	1.106	1.032
ARIZONA	1.033	1.036	0.997
ARKANSAS	1.211	1.175	1.031
CALIFORNIA	1.047	1.000	1.047
COLORADO	1.094	1.001	1.092
CONNECTICUT	1.074	1.037	1.035
DELAWARE	0.996	0.984	1.011
FLORIDA	1.023	0.934	1.094
GEORGIA	1.170	1.058	1.105
IDAHO	1.067	1.049	1.016
ILLINOIS	1.043	0.982	1.061
INDIANA	1.089	1.053	1.034
IOWA	1.110	1.109	1.000
KANSAS	0.975	1.009	0.965
KENTUCKY	1.010	1.004	1.006
LOUISIANA	0.771	0.982	0.785
MAINE	1.228	1.097	1.118
MARYLAND	0.944	0.937	1.007
MASSACHU-SETTS	0.926	0.952	0.972
MICHIGAN	1.051	0.988	1.064
MINNESOTA	1.119	1.095	1.021
MISSISSIPPI	1.119	1.100	1.017
MISSOURI	1.107	1.002	1.104
MONTANA	0.992	1.135	0.874
NEBRASKA	1.051	1.093	0.961

TABLE 1 (Continued)

STATE	MALMCUM	EFFCHCUM	TECHCHCUM
NEVADA	1.065	1.067	0.998
NEW HAMPSHIRE	1.498	1.300	1.152
NEW JERSEY	1.104	1.000	1.104
NEW MEXICO	0.967	1.050	0.921
NEW YORK	0.941	1.000	0.941
NORTH CAROLINA	1.209	1.080	1.119
NORTH DAKOTA	0.985	1.180	0.834
OHIO	1.063	0.989	1.074
OKLAHOMA	0.930	0.972	0.956
OREGON	1.064	1.008	1.055
PENNSYLVANIA	1.054	0.961	1.096
RHODE ISLAND	0.929	1.000	0.929
SOUTH CAROLINA	1.122	1.044	1.075
SOUTH DAKOTA	1.070	1.139	0.939
TENNESSEE	1.238	1.165	1.062
TEXAS	1.055	1.065	0.990
UTAH	1.133	1.063	1.065
VERMONT	1.063	1.049	1.012
VIRGINIA	1.028	0.971	1.058
WASHINGTON	1.013	1.026	0.987
WEST VIRGINIA	0.895	0.968	0.924
WISCONSIN	1.171	1.068	1.096
WYOMING	0.735	1.000	0.735

Notes: These are the cumulated indexes over the 1970-1986 period, representing the total cumulated productivity growth over that period. It is the multiplicative cumulation of adjacent year indexes.

TABLE 2

Cumulated Productivity and Growth Rates of Inputs and Outputs by Region, 1970-1986

VARIABLE	TOTAL (48)	EAST (9)	N. CENTRAL (12)	SOUTH (16)	WEST (11)
Malmquist	1.057	1.091	1.070	1.055	1.019
Efficiency Change	1.044	1.045	1.059	1.035	1.040
Technical Change	1.012	1.040	1.013	1.018	0.981
GSP	0.031	0.031	0.023	0.031	0.038
Highway	0.011	0.002	0.008	0.016	0.014
Neighbors	0.010	0.002	0.009	0.014	0.012
Private Capital	0.020	0.025	0.020	0.022	0.014
Employment (Nonagricultural)	0.026	0.022	0.018	0.028	0.037
Service/Manufacturing	0.025	0.030	0.023	0.028	0.020
Private Capital/Labor	0.006	0.009	0.006	0.008	0.001
Highway/Private Capital	-0.019	-0.026	-0.013	-0.018	-0.021
Public Capital/Private Capital	-0.006	-0.011	-0.004	-0.009	0.001
Private Sector Share	0.002	0.002	0.002	0.002	0.002

Notes: The Malmquist index and its components are the means of the cumulated indexes for the entire 1970-1986 period.

The other variables are average annual growth rate. The Highway variable is own state highway capital stock weighted by area.

NEIGHBORS is the sum of immediately adjacent states' highway variable. ~~Private capital is weighted by population.~~

TABLE 3a
Parameter Estimates: Random Effects Model
Malmquist Index

	EAST		NORTH CENTRAL		SOUTH		WEST	
Variable	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]
Intercept	0.5699	0.0048	0.6545	0.0008	0.9315	0.0001	0.8645	0.0001
Boom	0.0162	0.0093	0.0281	0.0001	0.0168	0.0001	0.0244	0.0001
Recession	-0.0247	0.0018	-0.0433	0.0001	-0.0274	0.0001	-0.0299	0.0001
Service/Manu-facturing	-0.0031	0.8328	0.0063	0.1958	-0.0061	0.0166	0.0012	0.2524
Private Capital/Labor	-0.0003	0.8464	-0.0004	0.4818	-0.0004	0.0192	-0.0004	0.0024
Highway/ Private Capital	0.0303	0.6067	0.1143	0.1722	0.0418	0.4234	0.0085	0.8970
Public Capital/ Private Capital	0.0575	0.3915	0.0808	0.1258	0.0337	0.2635	-0.0089	0.7580
Private Sector Share	0.5053	0.0175	0.3543	0.0823	0.1049	0.0595	0.1861	0.0989
Neighbors	-0.0084	0.0378	0.0038	0.6346	-0.0067	0.0227	-0.0187	0.3922

TABLE 3b
Parameter Estimates: Random Effects Model
Efficiency Change Index

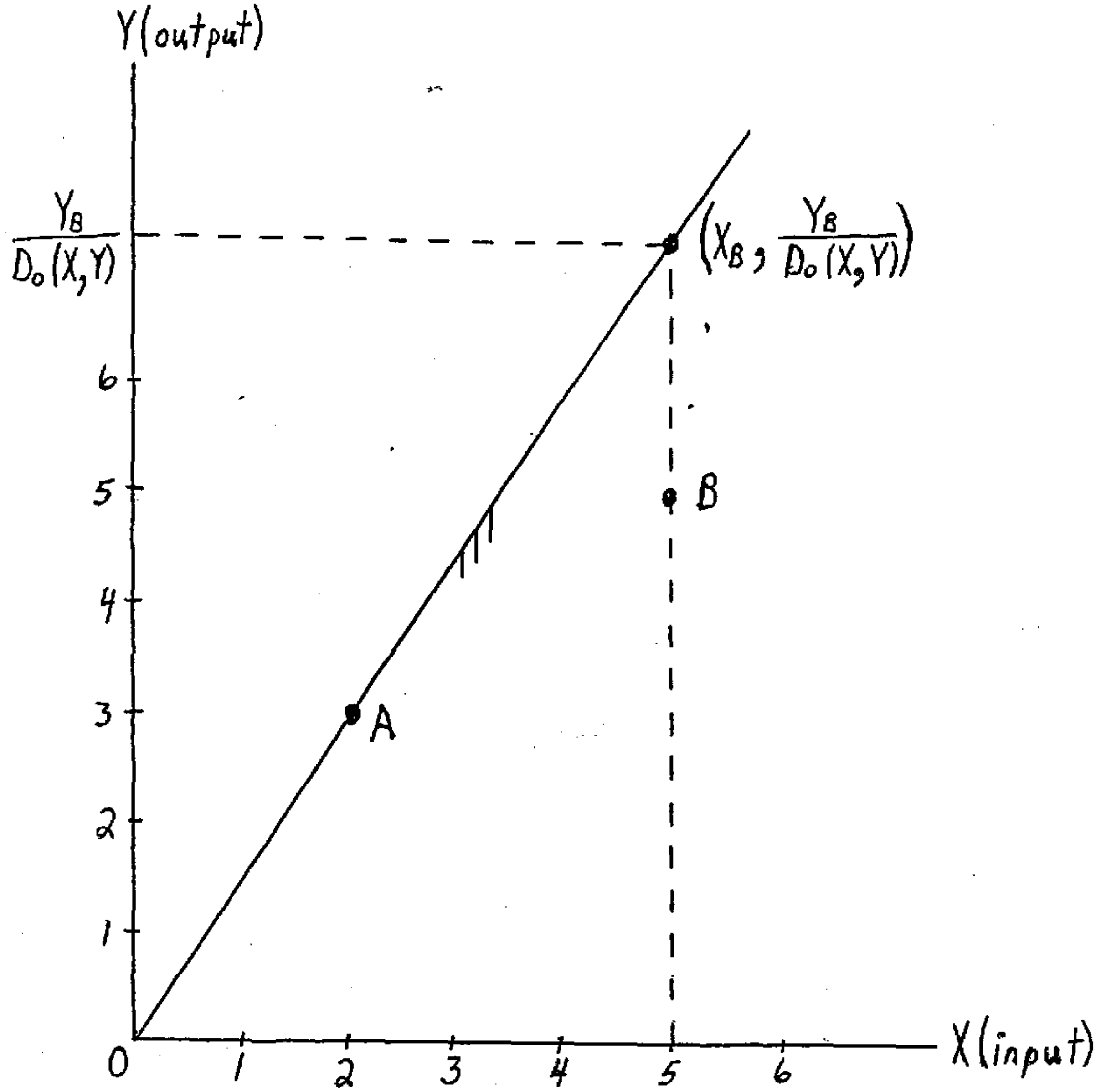
	EAST		NORTH CENTRAL		SOUTH		WEST	
Variable	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]
Intercept	0.8554	0.0001	0.7157	0.0001	0.9530	0.0001	1.0036	0.0001
Boom	0.0080	0.0741	0.0263	0.0001	0.0121	0.0011	0.0166	0.0004
Recession	-0.0074	0.1396	-0.0261	0.0001	-0.0089	0.0216	-0.0137	0.0035
Service/Manu-facturing	-0.0088	0.3590	-0.0006	0.8466	-0.0046	0.0390	0.0009	0.1940
Private Capital/Labor	-0.0012	0.2343	0.0005	0.1650	0.0000	0.9917	0.0000	0.7857
Highway/ Private Capital	0.0290	0.5123	0.1175	0.0301	0.0837	0.0936	0.0755	0.1571
Public Capital/ Private Capital	0.0198	0.6842	0.0728	0.0436	0.0107	0.6905	-0.0024	0.9035
Private Sector Share	0.2071	0.1778	0.2550	0.0942	0.0520	0.2922	-0.0200	0.8050
Neighbors	-0.0034	0.2734	0.0015	0.7648	-0.0063	0.0236	-0.0043	0.7654

TABLE 3c
Parameter Estimates: Random Effects Model
Technical Change Index

	EAST		NORTH CENTRAL		SOUTH		WEST	
Variable	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]	Parameter Estimate	Prob > [t]
Intercept	0.8286	0.0001	1.1061	0.0001	0.9719	0.0001	0.9082	0.0001
Boom	0.0071	0.2062	0.0011	0.7233	0.0031	0.2937	0.0046	0.2444
Recession	-0.0171	0.0173	-0.0139	0.0001	-0.0163	0.0001	-0.0137	0.0009
Service/Manu-facturing	-0.0027	0.9049	0.0065	0.0173	-0.0027	0.2407	0.0006	0.6015
Private Capital/Labor	-0.0013	0.4588	-0.0011	0.0002	-0.0004	0.0039	-0.0007	0.0001
Highway/ Private Capital	0.0005	0.4249	-0.0331	0.4778	-0.0436	0.3659	-0.0754	0.3251
Public Capital/ Private Capital	-0.0233	0.9437	-0.0333	0.2436	0.0250	0.3530	-0.0286	0.3803
Private Sector Share	0.0031	0.1504	-0.0600	0.5998	0.0649	0.1913	0.1729	0.1759
Neighbors	-0.0027	0.2055	0.0008	0.8572	-0.0009	0.7319	-0.0252	0.3554

FIGURE 1

The Distance Function and Best Practice Frontier



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